A Photovoltaic Solar Refrigeration System in a remote area for Vaccine Preservation

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ABSTRACT

According to a report by the World Health Organization, vaccines such as Diphtheria, Tetanus, Pertussis, Hepatitis A, Hepatitis B, Hib, Influenza, Meningococcal, Pneumococcal, and Rotavirus must be stored at refrigeration temperatures ranging from 2°C to 8°C. If these vaccines are stored outside of this temperature range, their effectiveness diminishes, leading to financial losses due to the high cost of vaccines. In remote regions lacking electricity, the preservation of vaccines poses a significant challenge. To address this issue, a portable refrigeration system utilizing the photovoltaic effect has been designed and developed. This system measures 24.50″×21.25″×14″ and has a capacity of 30 liters, capable of maintaining an evaporator temperature between 0°C and 8°C for 9 to 10 hours once fully charged. The battery requires approximately 6 to 8 hours to charge. The coefficient of performance (COP) of this refrigeration system is 3.19, and a techno-economic analysis indicates a payback period of 8 years, 5 months, and 6 days.

Keywords: *Solar Photovoltaic, Vaccine, Remote Areas & WHO*

INTRODUCTION

Among the various vaccines, such as MMR, Diphtheria, Tetanus, Pertussis, Hepatitis A, Hepatitis B, Hib, Influenza, IPV, Meningococcal, Pneumococcal, and Rotavirus, it is essential to maintain a temperature range of 0°C to 8°C for optimal preservation. Certain vaccines, including MMRV, Varicella, and Zoster, necessitate storage at freezer temperatures as low as -15°C. Deviating from these specified temperature ranges can compromise the potency of the vaccines, rendering them ineffective. Both excessive heat and cold can adversely affect vaccine efficacy, posing significant health risks to both children and adults. The financial implications are also considerable, with the cost of a single vaccine potentially reaching $280, highlighting the economic importance of proper vaccine storage. The primary cause of vaccine damage is inadequate storage practices. Therefore, maintaining vaccines at the required temperatures (0°C to 8°C) is crucial from two perspectives: (1) Economic Perspective: The expense of a single vaccine can be as high as $285, making it a significant investment. In traditional vaccine storage systems, it is common for 2-3 vaccines to be compromised in a single box over the course of a day during the summer months. (2) Health Perspective: Compromised vaccines can pose serious health risks to patients, with the potential for fatal outcomes. Numerous studies have been conducted on the viability of a Vapor Compression Refrigerator powered by solar photovoltaic panels. For instance, Modi, A. et al. [2] developed a solar refrigeration system utilizing a 165-liter LG vapor compression refrigerator and subsequently evaluated its performance. The operation of this system involves the use of specific devices.

- Two 12V 150 Ah Exide battery
- A charge control unit to overcome the problem of overcharging and deep discharging
- A transformer
- Four 75W solar panels.

Based on various experiments, it has been concluded that the coefficient of performance (COP) decreases from morning to afternoon, with a peak value of 2.012 recorded at 7 AM. The economic viability of this refrigeration system was assessed using the RET Screen analysis. The findings indicate that the solar panel constitutes one of the most significant expenses within this refrigeration system. The cost to generate 1 W of power is Rs. 80, and this system requires four 35 W solar panels, totaling Rs. 11,200. Therefore, it is essential to implement government subsidies for the solar panels. This entire study was conducted under the environmental conditions of Jaipur city, India.

Kattakayam, T. A. and Shrinivasan, K. [3] conducted an analysis on the efficiency of a 100 W AC-powered domestic vapor compression refrigeration system. This refrigerator operates using components such as a solar photovoltaic panel, a battery, and an inverter, which together generate a non-sinusoidal AC signal. Their findings indicate that the use of a non-sinusoidal AC signal does not adversely affect the thermal performance of the refrigerator. Furthermore, they observed that the thermal efficiency is enhanced through effective insulation of the refrigerator and the use of a vacuum-insulated solar panel, which minimizes heat loss. Vaccines are consistently stored away from the walls and door of the refrigerator. They recommend improvements to the design of the compressor motor in domestic refrigerators.

Sarbu, A. and Sebarchievici, C. [4] conducted a comprehensive analysis of various solar refrigeration systems, including photovoltaic solar refrigerators, thermo-electric solar refrigerators, thermo-mechanical solar refrigerators (steam jet refrigerators), solar absorption refrigerators, solar adsorption refrigerators, and desiccant solar cooling systems. Following their investigation, they evaluated the performance of each type of refrigerator. Initially, they compared the Coefficient of Performance (COP) of liquid desiccant solar cooling systems with that of solid desiccant solar cooling systems, concluding that the COP of the liquid desiccant system is superior. Furthermore, when comparing the COP of absorption and adsorption solar refrigerators, they determined that the absorption system exhibits a higher COP, although it operates at a higher temperature than the adsorption system. Notably, among all the solar refrigeration systems analyzed, the thermo-mechanical solar refrigerator (steam jet refrigeration system) demonstrated the highest COP and operating temperature compared to the other systems.

Nawaz, I. et al. [5] developed a solar refrigerator and subsequently conducted a cost and environmental impact analysis of this system. The findings indicate that a solar-powered refrigeration unit is more cost-effective than a conventional electric refrigeration system. Although the initial investment for the solar-powered system is significantly higher, it becomes more economical over time, ultimately proving to be less expensive than the electric system after a period of five years.

Biligili, M. [6] conducted an hourly simulation and assessed the performance of a solar electric-vapor compression refrigeration system. This study was carried out at various evaporator temperatures across different months in Adana, a city situated in the southern part of Turkey. The results indicated that at an evaporator temperature of 0°C, the peak compressor power consumption reached 2.53 kW at 15:00 on August 23. The necessary surface area for the photovoltaic panels was approximately 31.26 m².

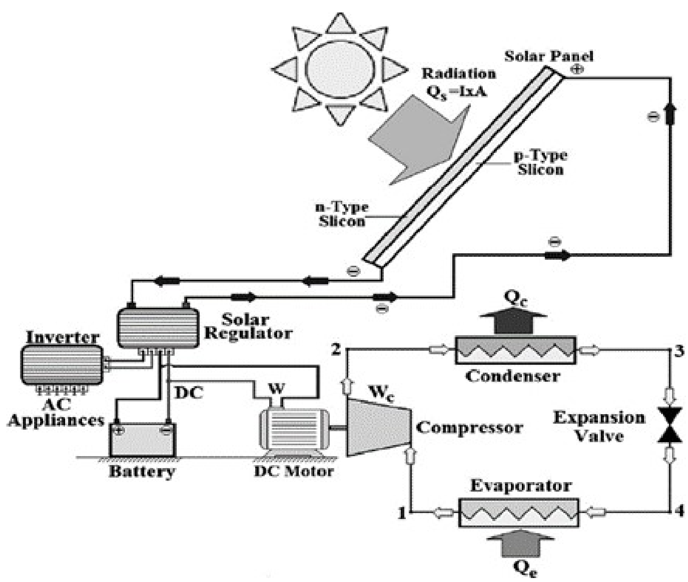

Figure 1: Solar Power Vapor Compression Refrigeration System for Hourly Simulation [6]

Cherif, A. and Dhouib, A. [7] conducted dynamic modeling and simulation of a photovoltaic refrigeration system utilizing hydraulic storage (latent heat storage). By implementing hydraulic or latent heat storage, they eliminated the need for a battery bank in the photovoltaic solar refrigeration system. They evaluated the performance of a refrigeration system without batteries under various environmental conditions and subsequently compared the performance of the hydraulic storage refrigeration system with that of the battery storage refrigeration system.

Mba E. F. et al. [8] introduced a mathematical model for photovoltaic systems utilizing Mat Lab. This refrigeration system comprises a DC-powered compressor, a 12V battery, a solar panel, and a charge control unit designed to prevent overcharging and deep discharging. An electrical analogy was established, where the output of one component serves as the input for another. The mathematical simulation was conducted using Mat Lab over a 12-hour period, revealing that as voltage increases, the battery size decreases. This analysis focused on the KC65T photovoltaic panel, and the mathematical modeling indicated that the SPV panel functions more as a current source than a voltage source. Additionally, an increase in solar panel insulation resulted in a higher power output due to the rise in current at a constant voltage of 14.2 V.

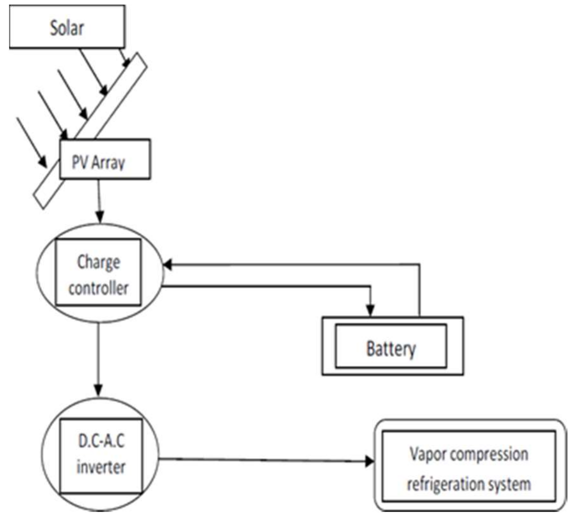

Figure 2: A DC Power Operated Refrigeration System [8]

Kim, D. and Ferreira, C. A. I [9] introduced an alternative refrigeration system that utilizes solar energy as its power source. They found that the Coefficient of Performance (COP) of a single absorption system surpasses that of both single effect adsorption systems and double effect absorption systems. While thermo-mechanical and photovoltaic solar refrigeration systems exhibit a better COP than absorption systems, their initial installation costs are significantly higher. Additionally, desiccant systems are more expensive compared to other refrigeration systems.

Kablanis, S. and Papanastasiou, N. [10] enhanced a traditional refrigerator by integrating a solar photovoltaic (SPV) panel and subsequently evaluated the performance of this upgraded appliance. The primary alteration involves replacing the conventional AC compressor with a DC compressor, eliminating the necessity for an inverter to convert DC power to AC power. This DC compressor requires a small power battery, which is safeguarded against overcharging and deep discharging by a charge control unit. A significant benefit of this modification is a reduction in daily energy consumption by up to 1.53 kWh when the system operates for 15 hours each day. To minimize cable losses, the distances maintained are 1.5 meters between the SPV panel and the charge control unit, 1.5 meters between the battery and the charge control unit, and 6 meters between the charge control unit and the refrigerator.

The aforementioned studies have facilitated the development and design of a portable photovoltaic solar refrigeration system, allowing us to assess its performance specifically for the preservation of vaccines. The block diagram of our system is straightforward and easily comprehensible, as illustrated below:

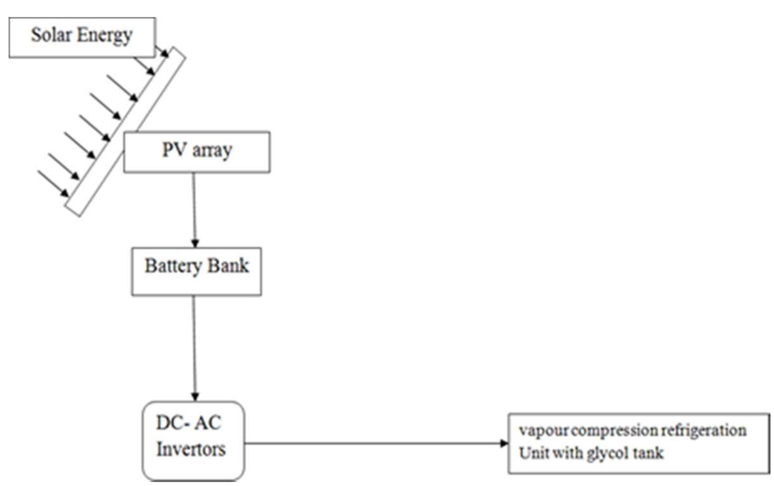

Figure 3: Photovoltaic Solar Refrigeration System

FABRICATION METHODS

A photovoltaic refrigerator system, which consists of five components: (1) the refrigeration unit, (2) the battery bank, (3) the inverter, (4) the solar panel, and (5) the moving frame.

1. A refrigeration unit operates using a basic vapor compression cycle, which consists of the following components:

a. Steel Tank: There are two tanks

- Outer Tank: A thick 14.47”×21.25”×14” outer steel tank with base in which 15kg mild steel sheet is used to make this tank.
- Inner Tank: A thin 8”×14”×10” inner steel tank in which 15kg mild steel sheet is used to make this tank. This is actually that space in which vaccine will be kept. The capacity of this inner tank is approximately 25-30 liters.

b. Accessory Box: An accessory box is also attached with this refrigeration unit on the backside to keep extra items other than vaccines.

2. The evaporator is constructed using a 100-foot long copper tube with a diameter of 5/16 inch, which is coiled around an inner steel tank. The low-pressure, low-temperature liquid refrigerant R134a flows through this copper coil, absorbing heat and transforming into vapor. This vapor then proceeds to the compressor.

3. The design of the compressor involves the compression of low-pressure and low-temperature vapor refrigerant R 134a, which is sourced from the evaporator. This refrigerant is transformed into a high-pressure and high-temperature vapor through the compression process. Subsequently, this vapor is directed to a condenser. For the compression task, a hermetically sealed THK compressor, model number 1340, is utilized. Further details regarding the compressor are provided below:

Manufactured by	**Tecumseh**
Model no.	THK 1340
Number of cylinder	1
Displacement per revolution	4 cc
Cooling cpacity	350 btu
Rated condition current	0.67 amps
Power	90 watts
Weight	7.7 kg

4. The design of the condenser involves the transformation of high-temperature, high-pressure vapor R134a refrigerant into a high-temperature, high-pressure liquid refrigerant through the condensation process as it exits the compressor and enters the condenser. A condenser measuring 7"×8" with two rows of 12 pipes is utilized for this condensation process.

5. The design of the expansion device involves the isenthalpic expansion of high-pressure, high-temperature liquid refrigerant as it flows from the condenser. This process transforms the refrigerant into a low-pressure, low-temperature liquid. The capillary tube used in this system measures 11 feet in length and has a diameter of 0.0036 inches.

6. The design of a fan involves utilizing a 10-watt fan to improve the rate of condensation.

7. A thermostat serves the purpose of regulating and monitoring temperature.

8. The process of refrigerant charging involves the use of 250 ml of R134a, which is a modern and environmentally friendly refrigerant commonly utilized today.

9. The insulation design utilizes Polyurethane Foam (PUF) as the insulating material. The process of filling the PUF is challenging, with 5 kg of PUF being placed between the tanks, resulting in a 2.5-inch thick layer formed between them.

10. This project utilizes a 75 Ah 12 V Exide battery, which stores the DC power generated by the solar panel. The battery serves to stabilize both current and voltage during variations in solar power output.

11. The photovoltaic arrays consist of a 125W model No-HB125 positioned on the upper side of the frame. These arrays are angled at 45 degrees towards the south to optimize power generation. A standard solar photovoltaic panel is made up of interconnected photovoltaic cells, which are composed of semiconductor material and encased in protective glass, linked to a load. When sunlight strikes the semiconductor, it excites the electrons. These energized electrons are then separated by an internal field present in the semiconductor and collected into an external circuit, thereby producing electricity. Multiple interconnected photovoltaic cells create a photovoltaic module, and several modules together form a photovoltaic array.

12. This project utilizes a 650 VA Microtech Inverter, which serves three primary functions: it operates an AC compressor, converts the direct current (DC) power generated by the solar panel into alternating current (AC), and facilitates the overall

energy management of the system.

13. This inverter is equipped with a charge control unit designed to safeguard the battery against overcharging and excessive discharging. To initiate the compressor, a power supply of 350 W is necessary. Given that the 650 VA inverter provides around 550 W, it is adequate for starting the compressor.

14. The dimensions of the solar panel are 26 inches by 52 inches, while the refrigeration unit measures 24.5 inches by 21.25 inches by 14 inches. Consequently, we have chosen a frame base measuring 28 inches by 52 inches. To achieve a 45-degree angle, one edge is elevated to a height of 24 inches, while the opposite edge is raised to a height of 14 inches.

RESULTS AND ANALYSIS

LOAD ANALYSIS

Compressor

A 90Watts modal No-THK 1340 is used as the compressor of company Tecumseh Refrigeration Equipment.

- Input power= 90Watts

Fan

A fan is used for cooling purpose of the compressor.

- Power of fan=10Watts
- Total power required (compressor +fan) =90+10 =100Watts

Battery Bank

To overcome the inertia of compressor & fan and considering wire losses power delivered by the battery must be higher than 80W. So we selected a 12V 80Ah rechargeable Exide battery model No-DB-12-80.

- Power delivered by battery=VXI=12X80=960Watt-h
- Efficiency of battery=90%
- Net power output=960×0.9= 864Watt

Photovoltaic PV Array

We selected a 125-Watt solar panel on the topside of frame. The PV arrays are at 40deg angles in a south direction so maximum power is generated.

Power deliver by solar panel model No. HB12125= 125Watts

Inverter

Input power of compressor is 350 Watts. So we must select an inverter, which has output power higher than 350 Watts. In this project, we selected a 650 VA micro tech inverter and power delivered by this inverter is approximately 550 Watts which is higher than 350 Watts.

CONCLUSIONS

Through our system's experimentation, we have determined that the developed system can sustain the necessary temperature range (0°C to 8°C) for up to 10 hours without any external power supply. The system is environmentally friendly as it utilizes R134a as a refrigerant. We conclude that it is feasible to implement a vapor compression cycle refrigeration system powered exclusively by solar panels for the effective preservation of vaccines in remote areas. We recommend substituting a DC compressor for the AC compressor, which may lower power requirements, enabling the use of a smaller capacity battery and a more economical charge control unit instead of an inverter.

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